CPW-Fed Reconfigurable Clover-Shaped Antenna with Switchable Circular Polarization

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Abstract—In this paper, a CPW-fed reconfigurable clover-shaped antenna with switchable circular polarization is proposed. This antenna consists of a clover-shaped patch, four p-i-n diodes, and two pairs of quarter-circular-rings. By electrically controlling the four p-i-n diodes to form two orthogonal bow-tie shaped current paths, the proposed antenna can be operated in two modes: the left-hand circular polarization (LHCP) and right-hand circular polarization (RHCP) modes. Two pairs of quarter rings are used to improve the bandwidth and AR performance of the antenna. The measured 10-dB reflection coefficient and 3-dB axial-ratio (AR) bandwidth of the prototype antenna is approximately 12.3% and 19%, respectively, which is enough for some wireless applications such as WLAN IEEE 802.11 b/g (4%). Gain and radiation pattern are also presented.

1. INTRODUCTION

Recently, great attention has been paid to polarization reconfigurable antennas, since they can mitigate the multipath effects [1], and expand the capabilities of the communication systems [2]. Many researches of polarization switchable antennas have been reported [3–15]. In general, the antennas with switchable polarization are designed to form at least two polarization states, like LHCP and RHCP, while the method to obtain polarization reconfigurability is mainly with the aid of switching devices such as RF MEMS or p-i-n diodes. The RF MEMS has the advantages of low impedance, low parasitic capacitance and low insertion loss [3]. However, the p-i-n diode is more widely used because of its cheaper cost, faster response time and low power handling [4].

In [5], two p-i-n diodes were placed in the slots' regions to attain reconfigurable polarization capability by controlling their states "ON" or "OFF". E-shaped patch antennas were proposed in [6, 7], they achieved circular polarization diversity by using p-i-n diodes and RF MEMS, respectively. In [8], V-shaped coupling strip fed annular slot antennas with switchable polarization is reported, only two p-i-n diodes are involved in the reconfigurable design. The square-ring microstrip antennas was design for switchable circular polarization in [9, 10]. By adjusting the states of two diodes, the operating mode of the antenna can be electrically switched. Using some special feed structures can also achieve circular polarization [11, 12]. By electrically controlling the p-i-n diodes connected to the Y-shaped and T-shaped feeding line respectively, polarization reconfigurable antennas were obtained. CPW-fed planar antennas were widely used in reconfigurable antenna designs due to their simple structure [13–15]. In [13], a polarization reconfigurable CPW-fed slot antenna was proposed. The vertical and horizontal linear polarizations were obtained by changing the bias state of the two p-i-n diodes. Circular polarization diversity were realized in [14, 15]. In [14], by changing the bias states of the two PIN-diode embedded in the inverted-L-shape ground strips at the upper corner of square slots, RHCP and LHCP characteristics

can be fulfilled. By inserting meander-line strip in the radiating stub and two L-shaped slots in the ground plane, a multi-band frequency performance and dual circular polarization characteristic can be realized [15]. The multi-band function was controlled by using four PIN diodes in the meander-line, while the circular polarization performance was determined by the bias states of the PIN diodes which were connected with the slots.

In this paper, we present a CPW-fed reconfigurable clover-shaped antenna with switchable polarization. The antenna is easy to fabricate. By changing the polarity of the bias voltage which is connected to four leaves, the bias state of the four p-i-n diodes can be controlled and the antenna acts as two orthogonal bow-tie patches. Therefore, the antenna can exhibit RHCP and LHCP performances. The antenna has a wide impedance matching and AR bandwidth, and measured gain and other results are also presented to show the competitiveness of the proposed antenna for WLAN and other wireless applications.

2. ANTENNA DESIGN

Figure 1 shows the geometry of the antenna proposed in this paper. The clover-shaped radiation part of the antenna is fabricated on an FR4 dielectric substrate with a permittivity of 4.4, loss tangent 0.02 and a thickness of 0.8 mm. The antenna is fed by a CPW structure, and the ground surrounds the radiation part with two pairs of quarter rings at the two bottom corners. Four p-i-n diodes (#1, #2, #3 and #4, part number BAV64-02V) are set at the center of the four leaves. In the forward bias state, the equivalent circuit of the p-i-n diode is represented by a resistor of 2.1 ohm. On the other hand, in the reverse bias state, the equivalent circuit of the p-i-n diode is presented by a capacitor of 0.17 pF. The mechanism of applying bias to the four p-i-n diodes is explained as follows.

The diodes junction "G" is connected to the ground plane through a via-hole, and the voltage of "G" is set as 0 V. The bias voltage Vc is superimposed on the four leaves simultaneously by the four via-holes "a", "b", "c", "d". When the leaves are with positive voltage (slightly higher than 0 V for example 0.2 V), diodes #1 and #3 are in the ON state, while the other two diodes are in the OFF state. By the same principle, when the leaves are with negative voltage, diodes #2 and #4 are ON-state, the other two diodes are OFF-state. The proposed antenna can exhibit RHCP and LHCP on the basis of
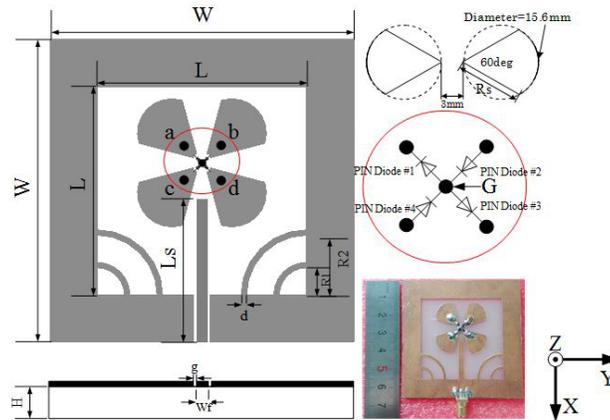
Figure 1. Geometry and photograph of the proposed antenna.

Table 1. The parameters of the antenna.

Parameter	W	L	H	g	W_f
Value (mm)	65	45	0.8	0.3	3
Parameter	R_s	L_s	R_1	R_2	d
Value (mm)	13.5	32	4	9	1

the bias states of the four p-i-n diodes.

The leaf of the clover is formed in the shape of a fan from a circle. The diameter of the circle is 15.6 mm, and the corner angle of the fan is 60 degrees. The gap between the two symmetry leaves (like #a and #d) is 3 mm, enough for two diodes. The parameters of the antenna are listed in Table 1.

The comparison between the proposed antenna and recently published polarization reconfigurable antennas from size and performance view is listed in Table 2. By comparison, the proposed antenna has a compact size and acceptable bandwidth performances.

Table 2. Comparison between the proposed antenna and the recently published reconfigurable antennas.

Reference antenna	Size (mm^3)	impedance bandwidth	AR bandwidth
Proposed antenna	$65 \times 65 \times 0.8$ ($0.49\lambda \times 0.49\lambda$)	2.28–2.58 GHz	2.04–2.60 GHz
[2]	$80 \times 80 \times 0.8$ ($0.63\lambda \times 0.63\lambda$)	24 GHz $\pm$ 30 MHz	2438 GHz $\pm$ 10 MHz
[6]	$140 \times 80 \times 0.787$ ($1.12\lambda \times 0.64\lambda$)	2.4 $\sim$ 2.575 GHz	2.38 $\sim$ 2.6 GHz
[8]	$100 \times 100 \times 1.6$ ($0.76\lambda \times 0.76\lambda$)	2.29 $\sim$ 2.60 GHz	2.408 $\sim$ 2.518 GHz
[11]	$70 \times 70 \times 1.6$ ($0.56\lambda \times 0.56\lambda$)	2.42 $\sim$ 2.56 GHz	2.48 $\sim$ 2.52 GHz
[12]	$70 \times 70 \times 1.6$ ($0.57\lambda \times 0.57\lambda$)	2.43 $\sim$ 2.72 GHz	2.615–2.67 GHz

(a)
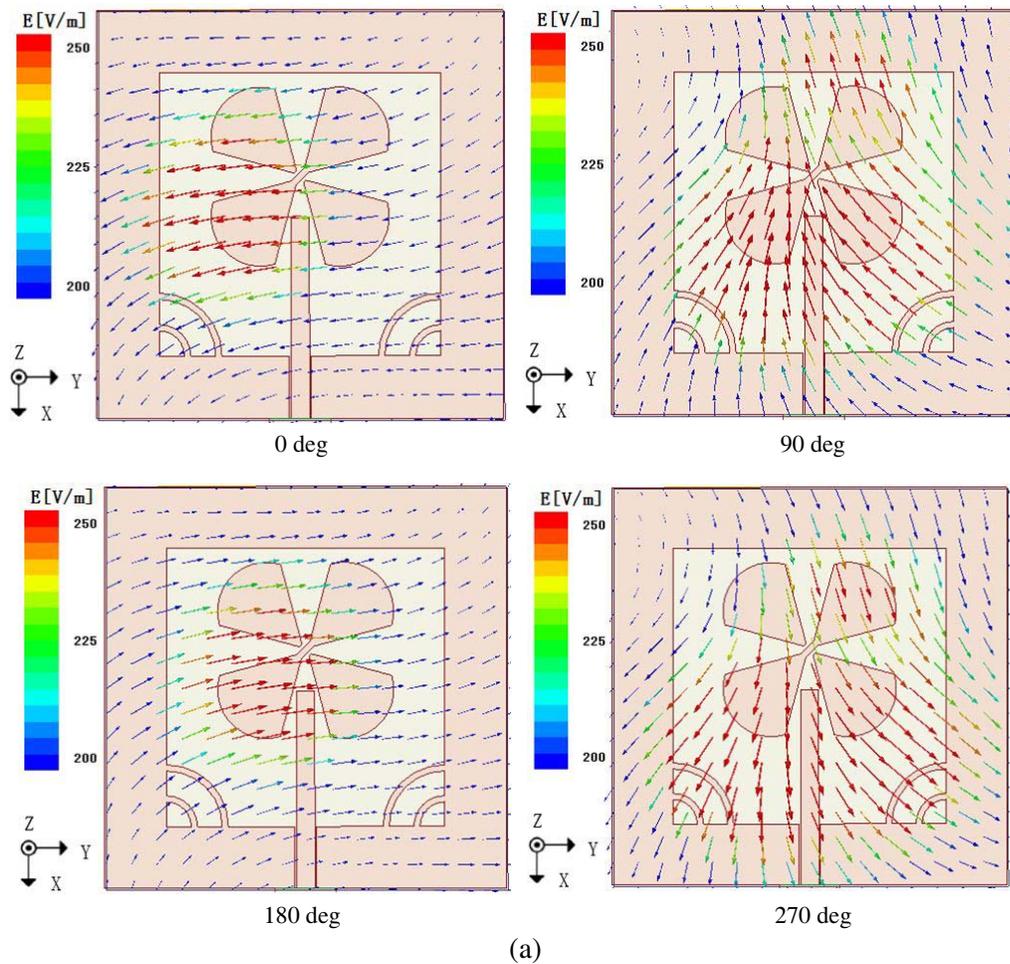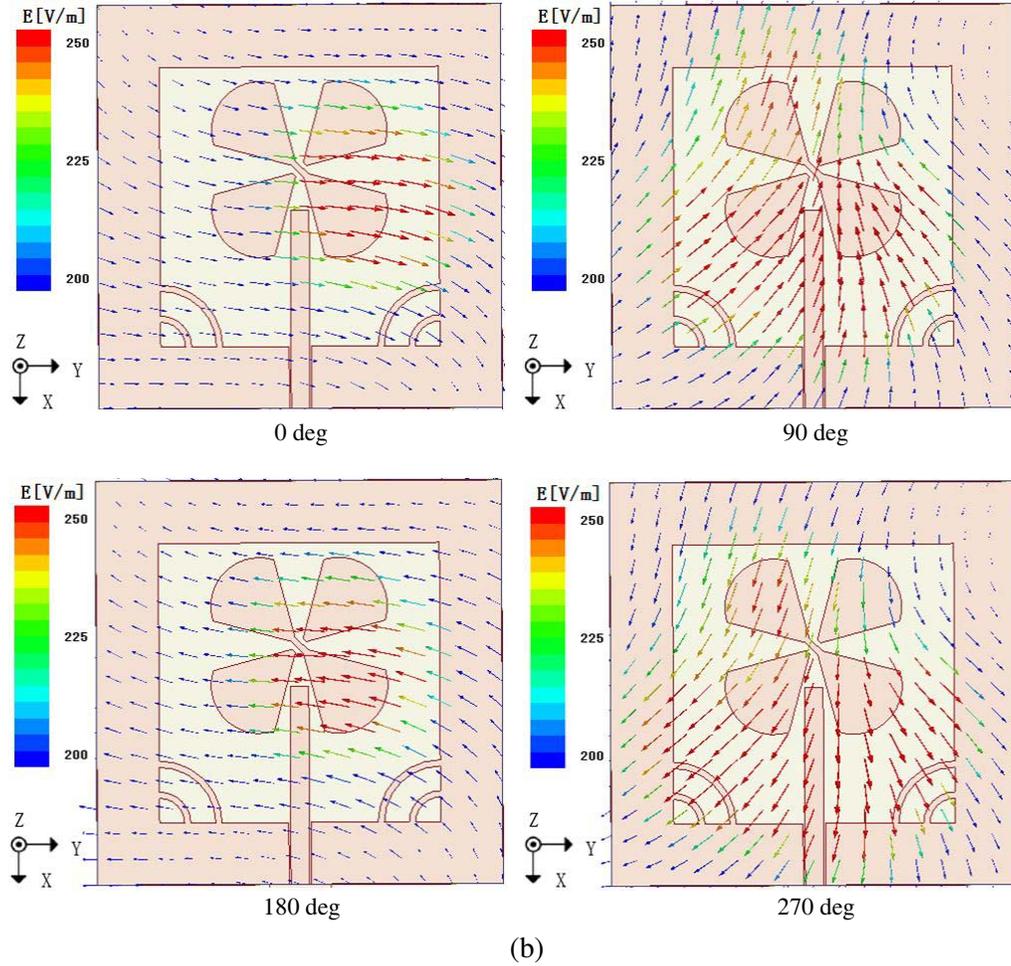
Figure 2. Simulated electric field vector on the proposed antenna at 2.45 GHz: (a) p-i-n diode #1 & #3 OFF- and #2 & 4 ON-state, (b) p-i-n diode #1 & #3 ON- and #2 & 4 OFF-state.

3. RESULTS AND DISCUSSION

Figures 2(a) and (b) show the simulated electric field vectors at a distance of 20 mm in the $+z$-axis direction of the antenna at 2.45 GHz for different phases. In Fig. 2(a), the p-i-n diodes #1 & #3 are OFF and #2 & #4 are ON. The two leaves which are connected with #2 & #4 are hold together like a bow-tie patch while the other two leaves are separated, the electric field vector rotates in the clockwise direction, and the antenna exhibits a LHCP property. Similarly, in Fig. 2(b), the p-i-n diodes #1 & #3 are ON and #2 & #4 are OFF, the antenna acts like a orthogonally crossed bow-tie patch and the electric field vector rotates in the anticlockwise direction which exhibits a RHCP property.

Figures 3(a) and (b) show the variation in reflection coefficient and the axial ratio of the proposed antenna with the change of the radius R_s of the leaves. As we can observe, the radius R_s affects both the resonance frequency and axial ratio. With the increase of R_s, the resonant frequency shifts to the lower frequency. The optimization for design was carried out through the simulations using the HFSS ver.15, the antenna can obtain desired performance at 2.45 GHz. The final clover radius is $R_s = 13.5$ mm.

Figure 4 shows the reflection coefficient and axial-ratio of the proposed antenna with the change of the length of the feeding line L_s. When the diodes (like #1 & #3 or #2 & #4) are ON, the bow-tie shaped patch is couple-fed by the feeding line, the length of the feeding line mainly affects the impedance matching of the proposed antenna. When the separation between the clover structure and the feeding line is big, the coupling between the two is weak, and no impedance matching bandwidth can be obtained. The AR bandwidth is also narrow.
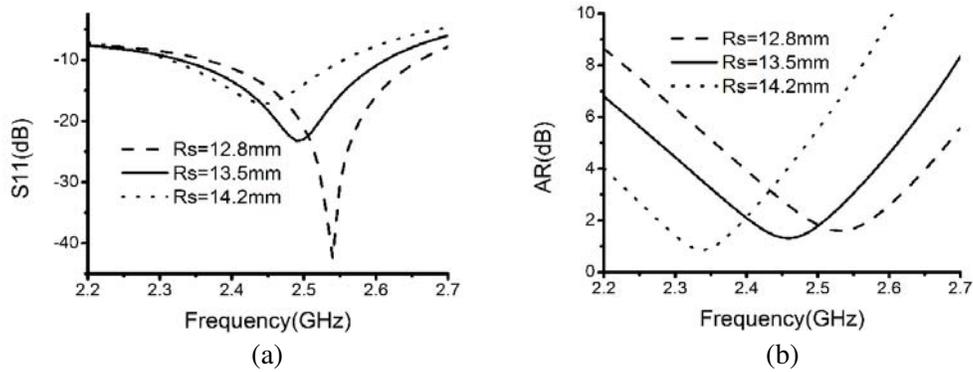
Figure 3. (a) Simulated reflection coefficient and (b) axial ratio of the proposed antenna for different value of R_s.
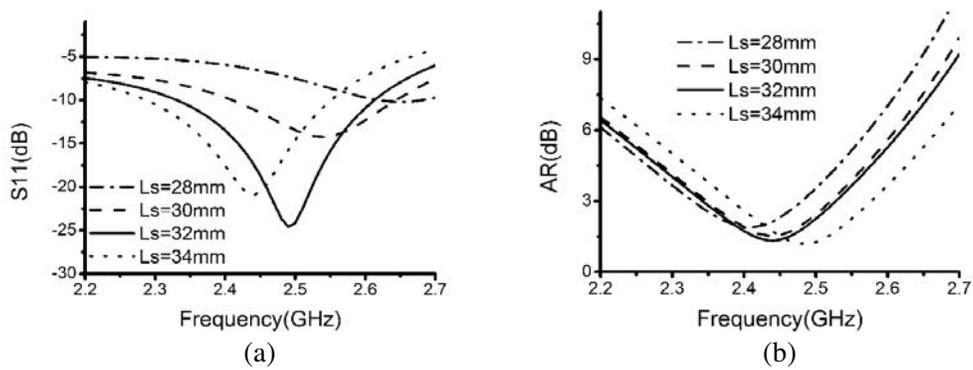
Figure 4. (a) Simulated reflection coefficient and (b) axial ratio of the proposed antenna for different value of L_s.
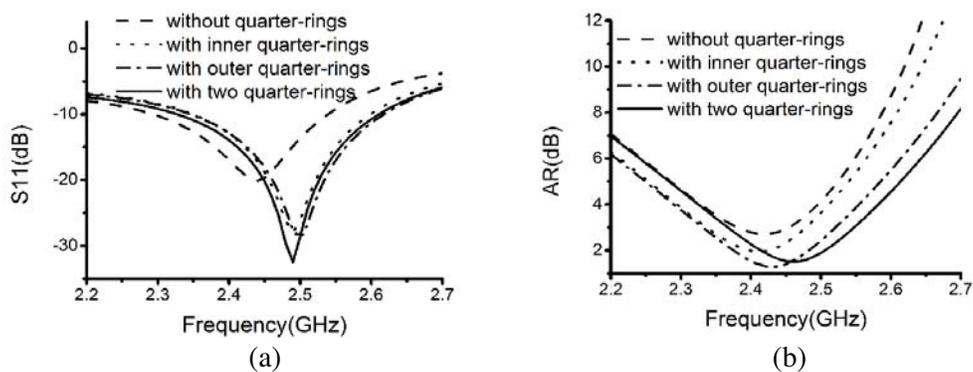
Figure 5. (a) Simulated reflection coefficient and (b) axial ratio of the proposed antenna with or without the quarter-circular-rings.

Figure 5 shows the reflection coefficient and the axial-ratio performances of the proposed antenna with the two pairs of quarter rings. The inner- and outer-quarter-rings have the similar effect on improving the impedance matching, but for AR bandwidth, the outer-quarter-rings have stronger influence on the antenna performances than the inner-quarter-rings.
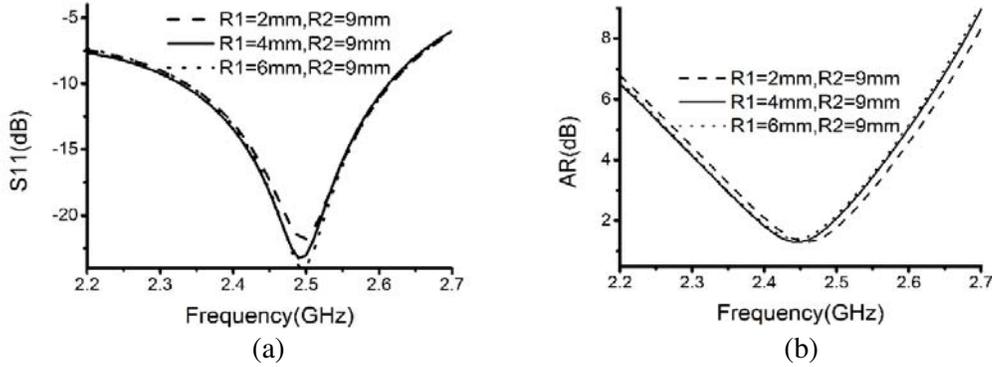
Figure 6. (a) Simulated reflection coefficient and (b) axial ratio of the proposed antenna for different value of R_1.
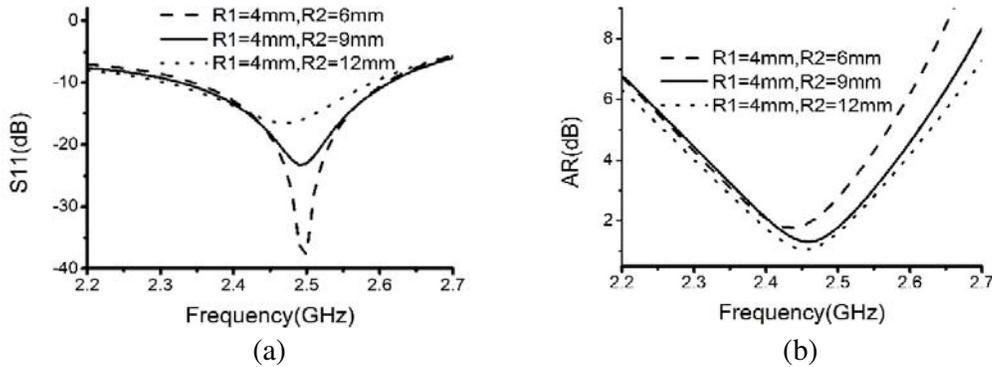
Figure 7. (a) Simulated reflection coefficient and (b) axial ratio of the proposed antenna for different value of R_2.

Figures 6 and 7 show the reflection coefficient and the axial-ratio of the proposed antenna with the change of the radius of inner-quarter-rings R_1 and outer-quarter-rings R_2, respectively. R_1 slightly affects the reflection coefficient and axial ratio of the antenna, and R_2 affects both the reflection coefficient and axial-ratio of the antenna more significantly. So in the antenna design, the inner-quarter-rings are for the fine-tuning and the outer-quarter-rings are for the coarse-tuning. With inner and outer rings together, the process of adjusting antenna matching becomes easier.

Figure 8 shows the measured and simulated reflection coefficients in two circular polarization modes. According to the result, for both modes, the antenna can obtain measured 10-dB impedance bandwidth 300 MHz (2.28–2.58 GHz, 12.3%) at the center frequency about 2.43 GHz. The differences between simulation and measurement are probably caused by fabrication imperfection and quality variances in the material.

The measured axial ratio is shown in the Fig. 9. When the proposed antenna operates in the LHCP mode, the 3-dB axial ratio bandwidth is about 24% (2.04–2.60 GHz), and the measured minimum axial ratio is 1.09 dB at 2.25 GHz. While for the RHCP mode, the 3-dB axial ratio bandwidth is about 19% (2.10–2.55 GHz), and the measured minimum axial ratio is 1.01 dB at 2.34 GHz.

Figures 10(a) and (b) show the measured radiation pattern when the antenna works in LHCP state and RHCP state at 2.45 GHz, respectively. The cross polarization level is high than 10 dB in the whole operating band.

The measured and simulated gains of the antenna are shown in Fig. 11(a). The measured gains when the proposed antenna operates in both LHCP and RHCP state are nearly the same. The gain is more than 2 dBi in all working frequencies with a peak gain of 3.89 dBi. The calculated efficiencies of the antenna in the operating band is no less than 88% and is shown in Fig. 11(b).
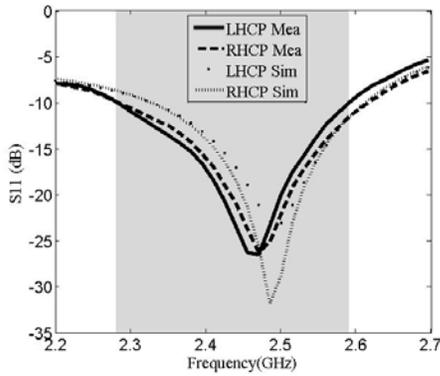
Figure 8. Simulated and measured reflection coefficient of the proposed antenna.
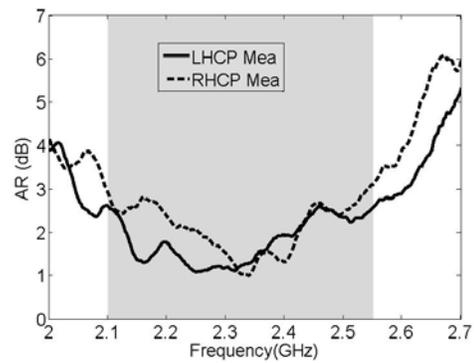
Figure 9. Measured axial ratio (AR) of the proposed antenna.

(a)

(b)

(c)
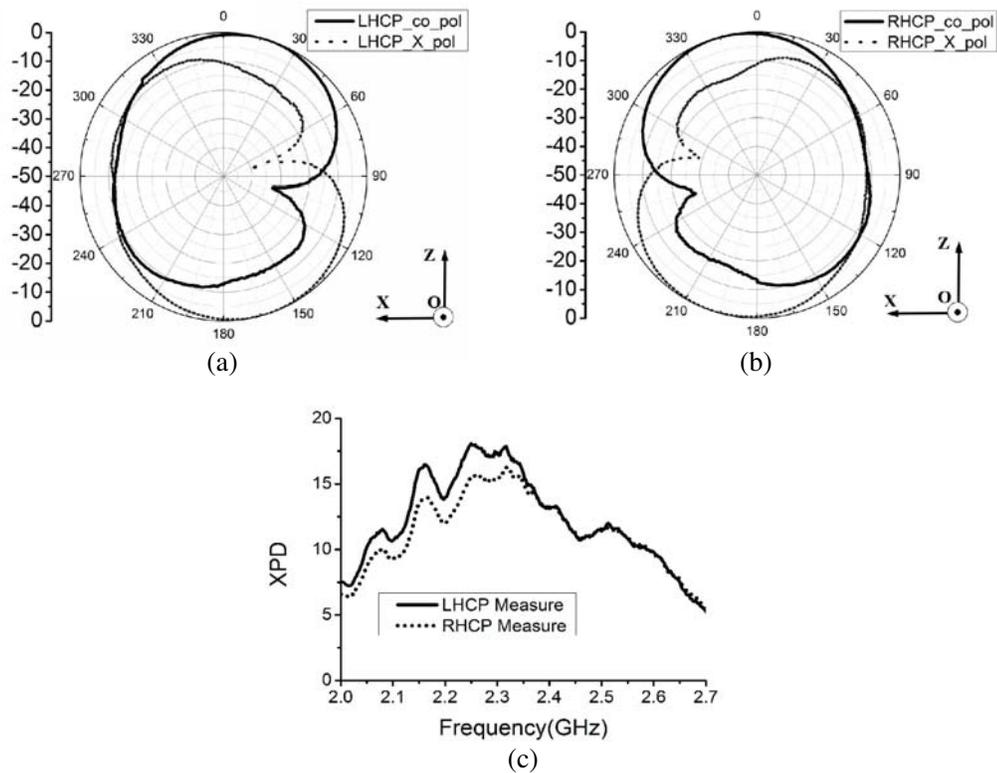
Figure 10. Measured radiation patterns of the proposed antenna at 2.45 GHz: (a) p-i-n diodes #1 & #3 ON and #2 & #4 OFF, (b) p-i-n diodes #2 & #4 ON and #1 & #3 OFF, (c) cross polarization level.

4. PRACTICAL APPLICATION

In wireless communication applications, unidirectional radiation is desired. Inspired by [16], a reflector consisting of a square metal plate and eight corner metal strips is placed at a distance of nearly $\lambda/4$ behind the reconfigurable antenna (Fig. 12(a)), and the unfolded picture of the reflector is shown in Fig. 12(b). The optimized parameters of the metal reflector are listed in Table 3. As shown in Fig. 13, the backward radiation is suppressed, while in Fig. 14, the gain at 2.45 GHz increases from 3.7 dBi to 5.99 dBi because of the metal reflector. Furthermore, as shown in Figs. 15(a) and (b), the impedance matching and AR characteristics are almost unchanged from the former design.
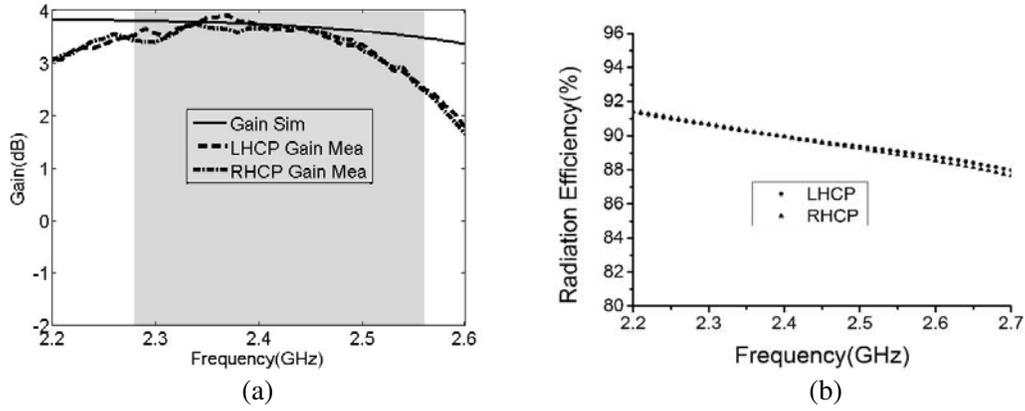
Figure 11. (a) Simulated and measured gain of the proposed antenna, (b) antenna efficiency.
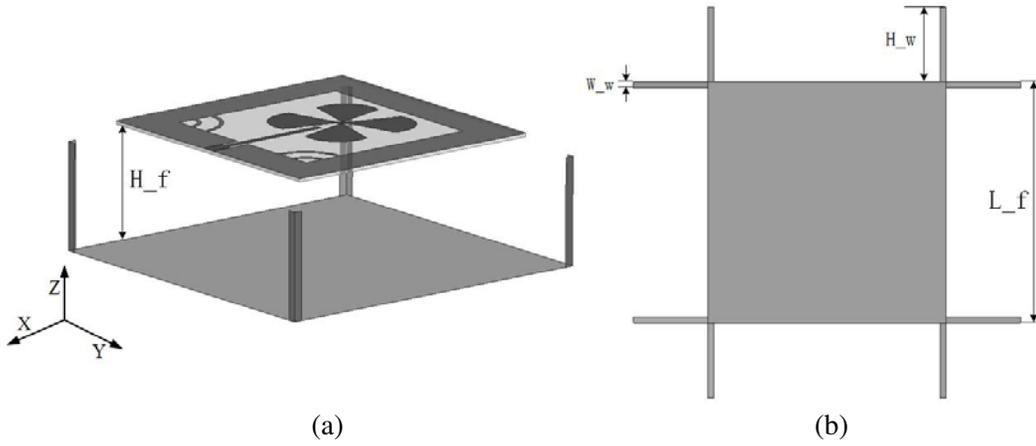
Figure 12. (a) Geometry and photograph of the proposed antenna with the reflector and (b) planar configuration of metal reflector.
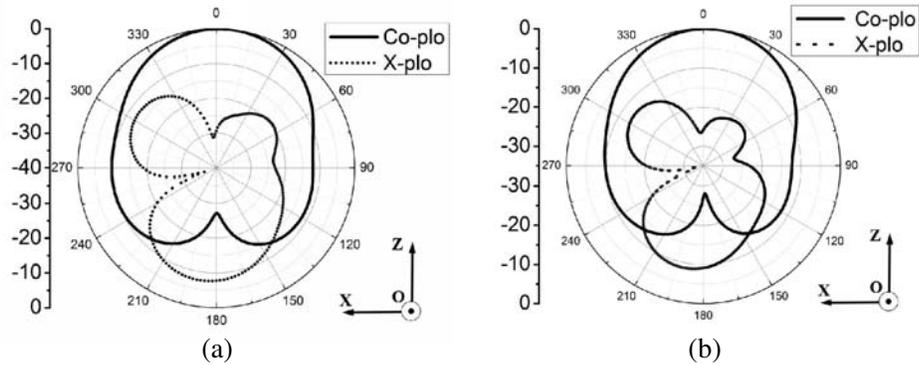
Figure 13. Simulated radiation patterns of the proposed antenna with the reflector at 2.45 GHz: (a) LHCP mode and (b) RHCP mode.

Table 3. The parameters of the reflector.

Parameter	L_f	H_f	W_w	H_w
Value (mm)	80	30	2	25
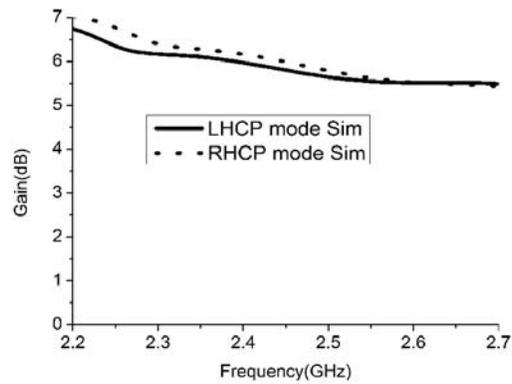
Figure 14. Simulated gain of the proposed antenna.

(a)	(b)
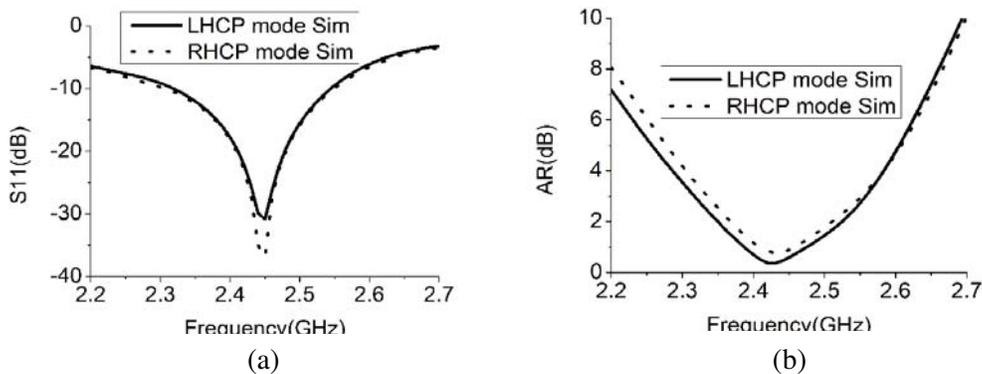
Figure 15. (a) Simulated reflection coefficient and (b) axial ratio of the proposed antenna with the reflector.

5. CONCLUSION

This paper proposes a CPW-fed clover-shaped antenna with reconfigurable circular polarization capabilities. The LHCP and RHCP modes are changed by adjusting the bias states of the four p-i-n diodes. By using two pairs of quarter rings, the measured 10-dB impedance bandwidth is 12.3%, and the 3-dB AR bandwidth is wider than 19%. Radiation pattern and antenna gain are also presented. The proposed antenna is competitive for WLAN and other applications.

ACKNOWLEDGMENT

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